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TERRY R. CLASON AND QUANG V. CAO

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TERRY R. CLASON[1] AND QUANG V. CAO[2]

Abstract

Tree volume data and equations that can be used in most areas of northwest Louisiana are presented. Data from 918 felled trees from seven loblolly pine plantations ranging in site index from 63 to 75 for base age 25 were used to develop a local product volume table. Performance of local product volume equations, which require only DBH to predict volume, was evaluated against standard and published volume equations, which require DBH and height. Local product volume equations can be used to provide reliable volume estimates for loblolly pine plantations in the multiproduct stage of development.

Introduction

A procurement forester's major responsibility is estimating pine timber volume and its value. Changing patterns in wood utilization makes the task of evaluating merchantable timber stands difficult. Equations that predict tree volume by product type would improve the accuracy of timber stand evaluations.

Local volume equations require only diameter at breast height (DBH) for volume predictions. Standard volume equations require both DBH and height measurements. By employing local volume equations rather than standard equations, the time saved by omitting height measurements could be used to measure additional tree diameters, thus providing a more reliable timber cruise.

A set of local volume equations designed to determine cubic-foot volume by product type in individual trees was developed for northwest Louisiana loblolly pine plantations. The product types were sawlogs, chip-n-saw, and pulp chips. Predicted volumes from these equations were comparable to those from standard and published volume equations.

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Procedures and Methods

Data

Individual taper data gathered from seven plantations were used in the study. The locations encompassed several soil types, such as Cuthbert gravelly sand, and Bowie, Ruston, and Shubuta fine sandy loams. Site indices ranged from 63 to 75 feet at base age 25. Some of the average stand parameters of each plantation are provided in Table 1. Measurements obtained from 918 felled trees included DBH, total height, and inside- and outside-bark diameters measured at 2′1″ intervals from a 6-inch stump to tree top. Sampled tree DBH and height distributions are shown in Table 2.

Table 1.—Stand characteristics of seven plantations located in northwest Louisiana

Location[1]	Age (Year)	Trees per acre	Site index base age 25 (Feet)	Number of trees sampled
1	22	450	65	284
2	29	200	68	437
3	22	450	65	30
4	15	375	75	40
5	22	500	67	40
6	15	475	63	40
7	29	300	70	47

[1]Sample trees from locations 1 through 6 formed the fit data set. Data from location 7 were withheld as a test data set.

Table 2.—Distribution of sample trees by DBH and height class

DBH (inches)	Total height (feet) 20	30	40	50	60	70	80	90	Total
	Number of sample trees								
4				1					1
6		2	26	54	31	3			116
8	2	4	16	87	96	51	2		258
10			2	17	73	130	25	1	248
12				4	30	69	55	1	159
14				2	14	35	38	6	95
16					4	14	16		34
18						3	2		5
20						2			2
Total	2	6	44	165	248	307	138	8	918

Cubic-foot product volumes were computed for individual trees based on the following merchantability standards:

1. Sawlog volume was cubic-foot volume inside bark (ib) from the stump to a top diameter ib greater than 7.5 inches with length being multiples of 8′4″ (four 2′1″ sections).
2. Chip-n-saw volume was cubic-foot volume ib from the last sawlog measurement to a top diameter ib greater than 4.5 inches with length being at least 8′4″ (four 2′1″ sections) and incremented by 2′1″.
3. Chip volume was cubic-foot volume ib from the last chip-n-saw measurement to a top diameter ib greater than 2.5 inches with length incremented by 2′1″.
4. Merchantable volume was the summation of sawlog, chip-n-saw, and chip volumes.

The specification of product type is illustrated in Figure 1. Volume for each 2′1″ section was calculated using the following conic formula:

$$V_i = 0.005454\ (D_i^2 + d_i^2 + D_i d_i)(L/3)$$

where V_i = cubic-foot volume of the ith section,

D_i = diameter ib in inches of the large end of the ith section,

d_i = diameter ib in inches of the small end of the ith section, and

L_i = length in feet of the ith section.

Individual tree product volumes were obtained by accumulating 2′1″ section volumes within each merchantability class.

Methods

The original data set was separated into a fit data set and a test data set. All 47 sample trees from location 7 (see Table 1) were withheld for the test data set because of a wide range in DBH. Data from the other six locations formed the fit data set.

Regression equations to predict tree product volumes from DBH (local volume equations) or from both DBH and total height (standard volume equations) were developed from the *fit data set*. The regression coefficients were then used to compute predicted volumes for trees in the *test data set,* which represented the population. Statistics from the set demonstrated how well the equations predicted the population.

In addition to equations developed from the fit data set, a combination of two published equations for loblolly pine was also evaluated. Smalley

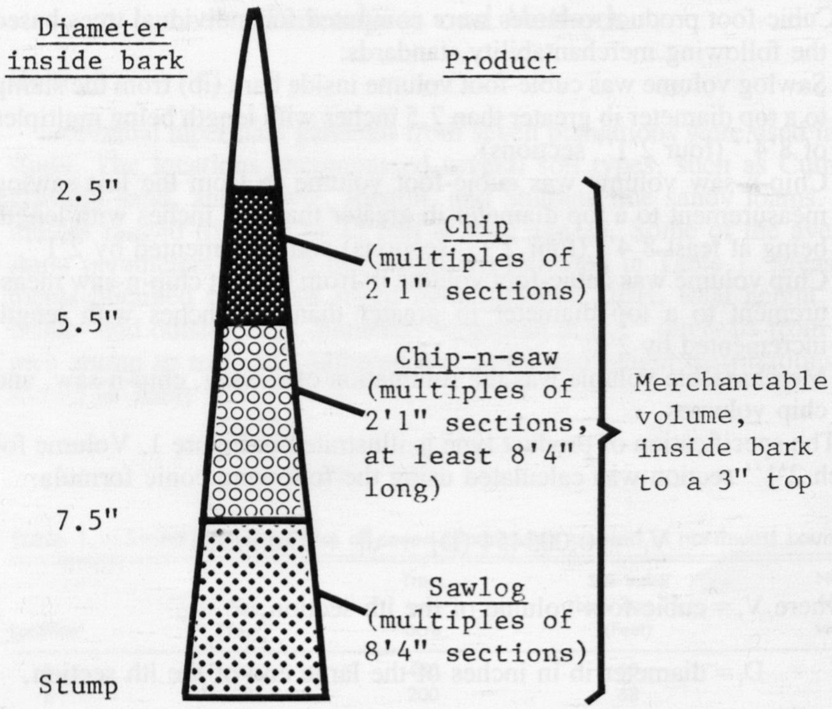

Fig. 1.—Product specifications.

and Bowe's (1968) equation to predict total volume ib (V) from DBH (D) and total height (H) is as follows:

$$V = -0.0709 + 0.0020695\ D^2H$$

Cubic-foot volume ib (v) to any top diameter (d) can be estimated using the above volume equation in conjunction with Burkhart's (1977) volume ratio model:

$$v/V = 1 - 0.82347\ d^{3.2822}\ D^{-3.0388}$$

Volume equations were evaluated by comparing observed and predicted tree volumes. Error % was computed to express reliability of predicted volumes for each equation, where:

Error % = 100 (Observed Volume − Predicted Volume)/
Observed Volume

Subsequently, the mean error % for each diameter class and for the entire test data set was calculated for each equation tested. If an equation produced large error % values of opposite signs, the result was a small average error % for all diameter classes which could bias reliability ratings. To account for this situation, the absolute error %, a value computed by disregarding sign and summing the weighed diameter class error %, was determined.

Table 3.—Local and standard volume equations developed from the fit data set for product volumes

Product type	Equation[1]
	------Local product volume equations------
Sawlog	$V_8 = -41.2013 + 4.5884\ D$
	$n=503;\ R^2=0.8960;\ s_{y.x}=3.20;\ \bar{V}_8=12.17$
Chip-n-saw	$V_5 = \begin{cases} -10.9238 + 2.0898\ D, & \text{if } D \leq 9.5'' , \\ 0.0080 + 805.1603/D^2, & \text{if } D > 9.5''. \end{cases}$
	$n=871;\ R^2=0.6493;\ s_{y.x}=1.49;\ \bar{V}_5=5.58$
Chip	$V_3 = 0.2866 + 51.2667/D^2$
	$n=871;\ R^2=0.4329;\ s_{y.x}=0.40;\ \bar{V}_3=0.94$
	------Standard product volume equations------
Sawlog	$V_8 = -10.0241 + 0.002254\ D^2H$
	$n=503;\ R^2=0.9174;\ s_{y.x}=2.85;\ \bar{V}_8=12.17$
Chip-n-saw	$V_5 = \begin{cases} -12.2692 + 1.6864\ D + 0.0796\ H, & \text{if } D \leq 9.5'' , \\ -6.4013 + 916.2825/D^2 + 0.0796\ H, & \text{if } D > 9.5''. \end{cases}$
	$n=871;\ R^2=0.7111;\ s_{y.x}=1.36;\ \bar{V}_5=5.58$
Chip	$V_3 = -0.8252 + 68.1284/D^2 + 0.0142\ H$
	$n=871;\ R^2=0.4820;\ s_{y.x}=0.38;\ \bar{V}_3=0.94$

[1]D = diameter at breast height in inches,
H = total height in feet, and
V = product volume in cubic feet.

Results and Discussion

Local and standard volume equations for products volumes based on the fit data set are shown in Table 3.

Equation-Fitting Process

Plotting product volumes versus total height or various combinations of DBH and height failed to suggest any strong relationship between product volumes and height. Consequently, the addition of total height as an additional variable improved the fit only slightly. Both local and standard volume equations were sufficient for estimating individual tree product volumes in loblolly pine plantations. Product volumes observed and predicted from local volume equations are shown in Figures 2 through 4. These graphs show that, despite considerable variation in the fit data set, the local equations followed the general trends apparent from the relationship between product volumes and DBH.

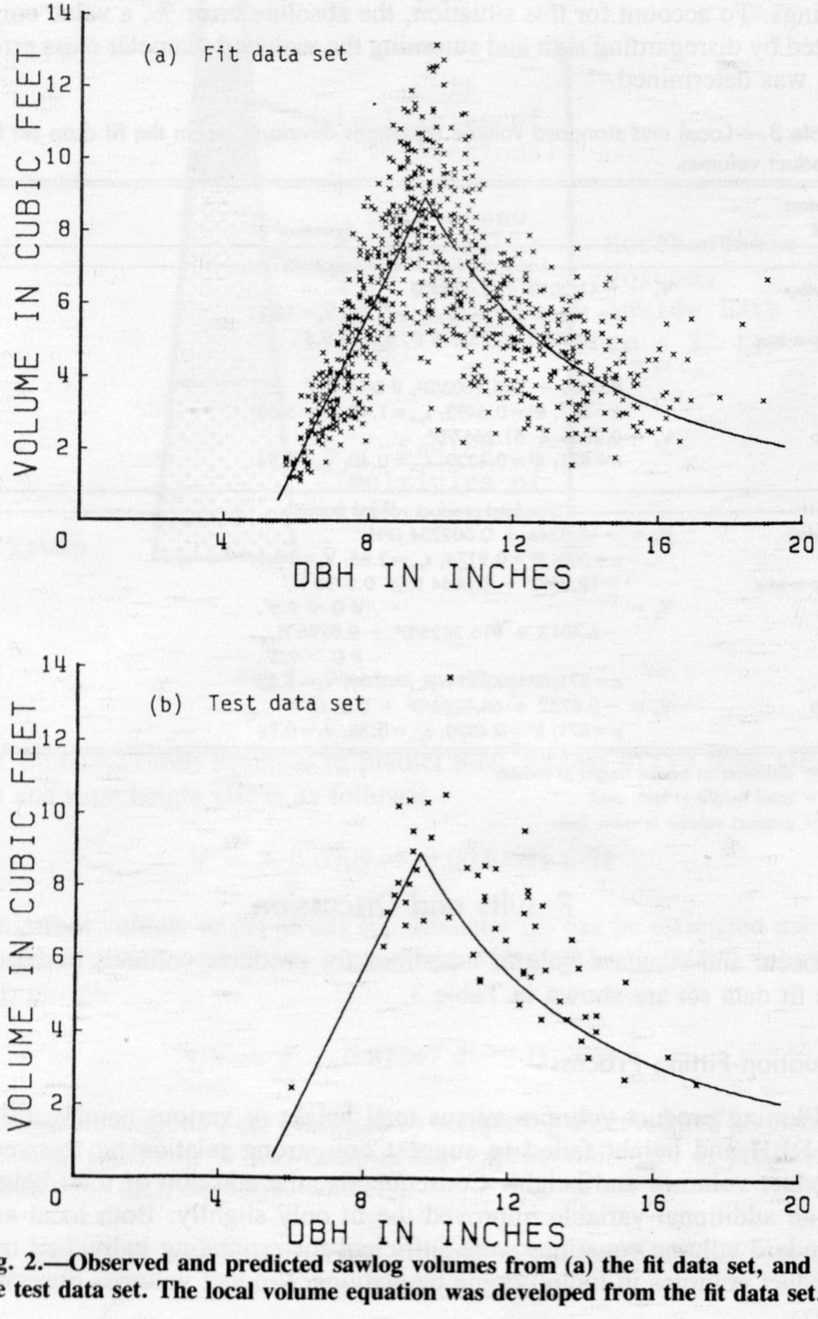

Fig. 2.—Observed and predicted sawlog volumes from (a) the fit data set, and (b) the test data set. The local volume equation was developed from the fit data set.

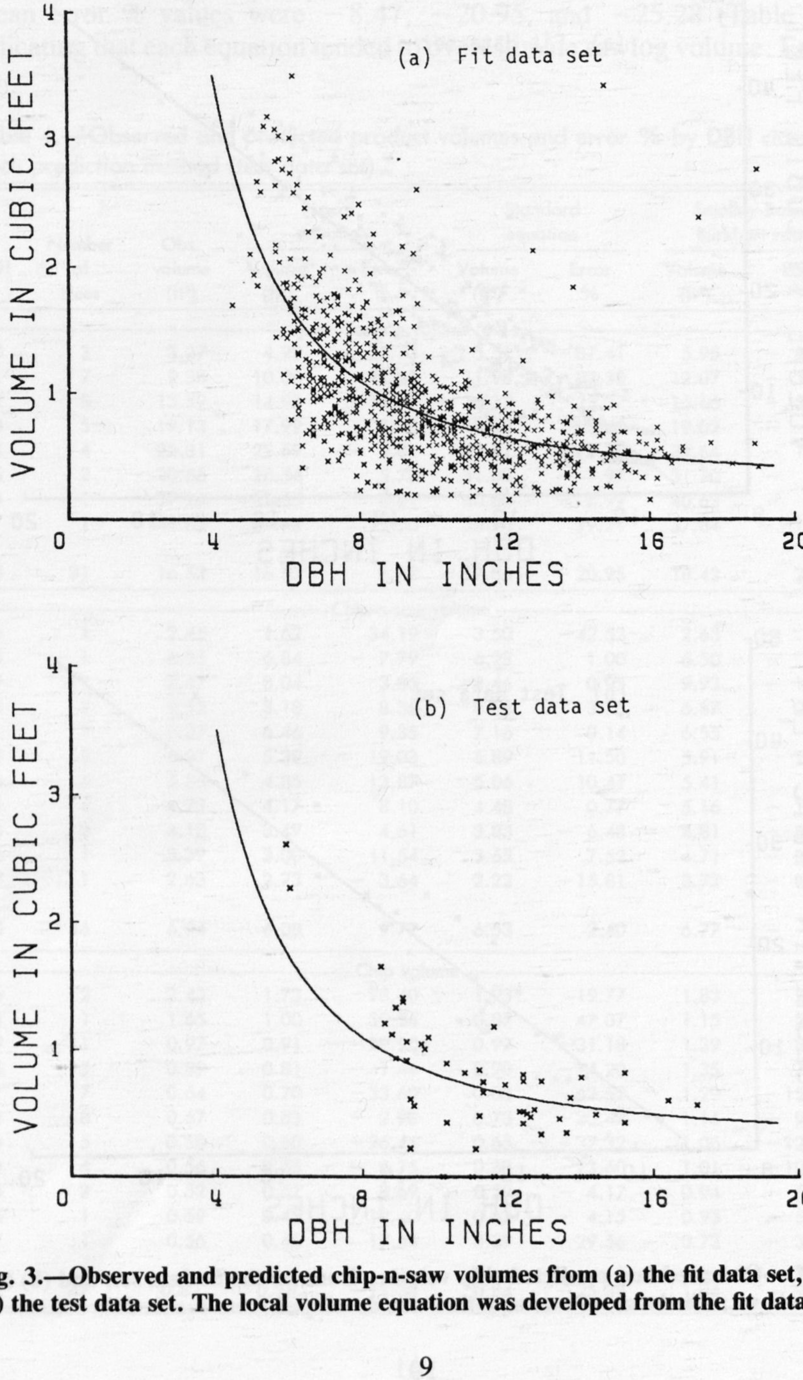

Fig. 3.—Observed and predicted chip-n-saw volumes from (a) the fit data set, and (b) the test data set. The local volume equation was developed from the fit data set.

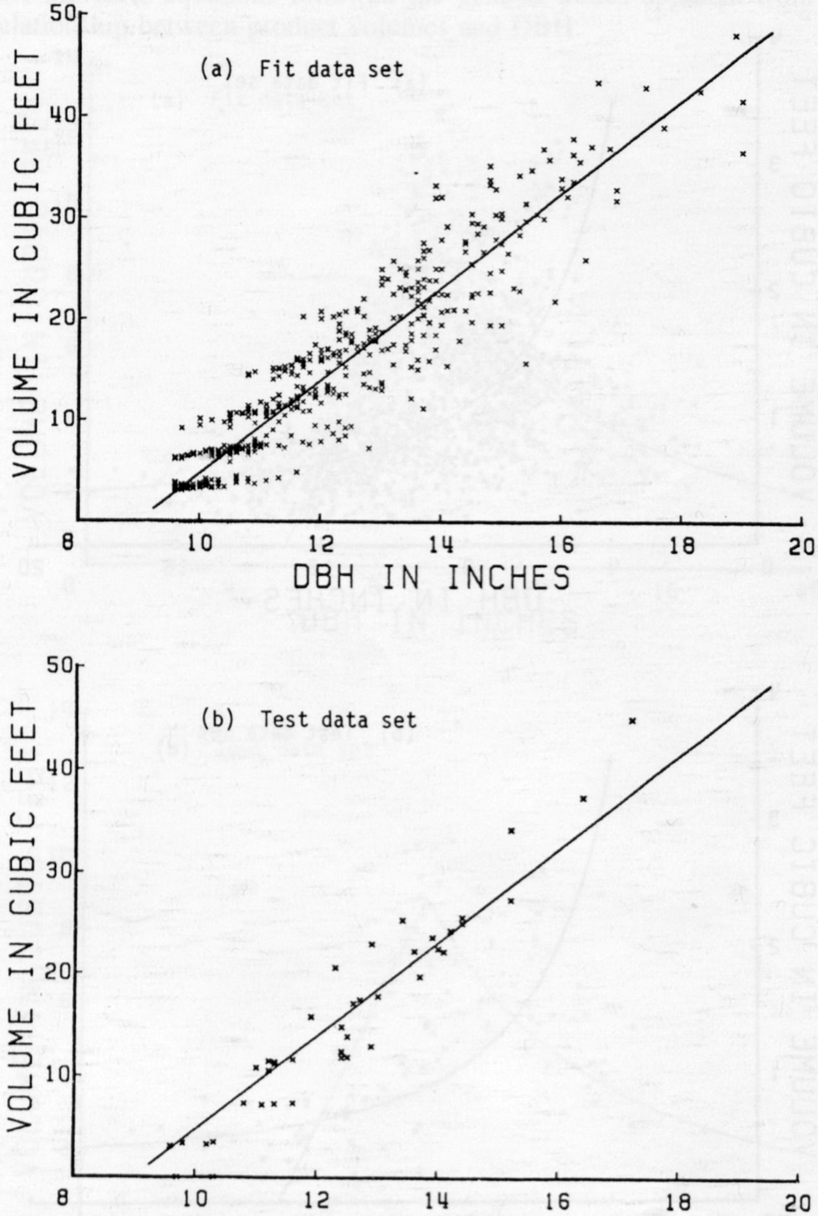

Fig. 4.—Observed and predicted chip volumes from (a) the fit data set, and (b) the test data set. The local volume equation was developed from the fit data set.

Equation-Testing Process

Sawlog volumes predicted from the local volume equations were comparable with those predicted from the standard and published equations. Mean error % values were −8.47, −20.95, and −25.28 (Table 4), indicating that each equation tended to overestimate sawlog volume. Error

Table 4.—Observed and predicted product volumes and error % by DBH class for each prediction method (test data set)

			Local equation		Standard equation		Smalley-Bower Burkhart ratio	
DBH in.	Number of trees	Obs. volume (ft^3)	Volume (ft^3)	Error %	Volume (ft^3)	Error %	Volume (ft^3)	Error %
			Sawlog volume					
10	3	3.27	4.22	−27.73	5.51	−67.41	5.95	− 80.78
11	7	9.38	10.06	−11.33	11.98	−32.38	12.07	− 33.51
12	8	13.59	14.95	−16.87	16.13	−25.37	16.66	− 29.91
13	5	19.13	17.99	1.38	18.02	0.69	19.02	− 4.67
14	4	22.31	22.69	− 2.01	23.81	− 6.78	24.64	− 10.59
15	2	30.66	28.54	5.72	31.02	− 1.97	31.70	− 4.32
16	1	37.26	34.05	8.61	40.60	− 8.99	40.62	− 9.02
17	1	44.88	37.72	15.96	36.26	19.21	37.84	15.69
All	31	16.53	16.52	− 8.47	17.86	−20.95	18.42	− 25.28
			Chip-n-saw volume					
6	1	2.45	1.62	34.19	3.50	−42.53	2.63	− 7.30
8	1	6.35	6.84	− 7.79	6.28	1.00	6.50	− 2.50
9	11	8.47	8.04	3.85	8.46	− 0.95	9.93	− 18.24
10	5	9.52	8.18	8.36	8.68	3.75	6.87	24.26
11	7	7.37	6.46	9.35	7.16	0.14	6.55	8.68
12	8	6.97	5.39	19.03	5.89	11.50	5.91	11.02
13	5	5.85	4.85	13.87	5.06	10.41	5.41	4.06
14	4	4.72	4.17	8.10	4.48	0.77	5.16	− 14.46
15	2	4.10	3.49	4.61	3.83	− 6.48	4.81	− 32.61
16	1	3.39	3.00	11.54	3.65	7.52	4.71	− 38.72
17	1	2.63	2.73	− 3.64	2.22	−15.81	3.72	− 41.36
All	46	6.94	6.08	9.72	6.53	2.40	6.77	− 2.68
			Chip volume					
6	2	2.43	1.73	28.40	1.93	19.77	1.83	23.42
8	1	1.65	1.00	39.54	0.87	47.07	1.15	29.96
9	11	0.97	0.91	−22.90	0.97	−31.18	1.39	− 88.63
10	5	0.89	0.81	− 1.44	0.90	−14.20	1.35	− 71.93
11	7	0.64	0.70	−33.60	0.83	−62.52	1.29	−150.09
12	8	0.67	0.63	− 2.98	0.73	−20.47	1.16	− 90.99
13	5	0.50	0.60	−26.44	0.65	−37.32	1.06	−125.34
14	4	0.56	0.55	− 8.75	0.63	−23.60	1.01	−100.10
15	2	0.62	0.51	8.69	0.59	− 4.17	0.94	− 67.97
16	1	0.59	0.48	19.40	0.62	− 4.15	0.93	− 56.33
17	1	0.56	0.46	17.54	0.39	29.56	0.73	− 31.25
All	47	0.82	0.76	−11.38	0.84	−25.38	1.24	− 91.21

Table 5.—Mean error % and mean absolute error % by product type for each prediction method

Product type	Local equation	Standard equation	Smalley-Bower Burkhart's ratio
	Mean error %		
Sawlog	− 8.47	− 20.95	− 25.28
Chip-n-saw	9.72	2.40	− 2.68
Chip	− 11.38	− 25.38	− 91.21
Merchantable volume	1.98	− 11.03	− 10.75
	Mean absolute error %		
Sawlog	18.90	27.17	29.92
Chip-n-saw	16.88	15.38	21.09
Chip	36.41	42.48	94.76
Merchantable volume	9.91	14.75	13.12

Table 6.—Local product volume table for loblolly pine planted in northwest Louisiana

DHB (inches)	Sawlog[1] volume	Chip-n-saw[2] volume	Chip[3] volume	Total[4] volume
	Cubic feet			
5			2.36	2.36
6		1.59	1.72	3.31
7		3.70	1.34	5.04
8		5.81	1.09	6.90
9		7.92	0.92	8.84
10	4.61	8.11	0.80	13.52
11	9.23	6.73	0.71	16.67
12	13.86	5.67	0.64	20.17
13	18.49	4.85	0.59	23.93
14	23.11	4.20	0.55	27.86
15	27.74	3.67	0.51	31.93
16	32.37	3.25	0.49	36.10
17	36.99	2.89	0.46	40.35
18	41.62	2.59	0.44	44.65
19	46.25	2.34	0.43	49.02

[1]Sawlog volume:

$$V_8 = -41.6645 + 4.6270\,D$$

$$n=543;\ R^2=0.8985;\ s_{y.x}=3.18;\ \bar{V}_8=12.24$$

[2]Chip-n-saw volume:

$$V_5 = \begin{cases} -11.0608 + 2.1091\,D, & \text{if } D \leq 9.5'', \\ 0.1237 + 798.9149/D^2, & \text{if } D > 9.5''. \end{cases}$$

$$n=918;\ R^2=0.6477;\ s_{y.x}=1.50;\ \bar{V}_5=5.64$$

[3]Chip volume:

$$V_3 = 0.2830 + 51.8171/D^2$$

$$n=918;\ R^2=0.4412;\ s_{y.x}=0.39;\ \bar{V}_3=0.93$$

[4]Merchantable volume $= V_8 + V_5 + V_3$

% values by diameter class showed that local volume equation performance was superior within the 10- to 14-inch diameter class range. Trees in this range accounted for 87 percent of the total number of trees with sawlog volumes in the test data set. A comparison of mean absolute error % (Table 5) demonstrated that the local volume equation was better in predicting sawlog volumes.

Both standard and published equations predicted *chip-n-saw volumes* more accurately than did the local equation. Mean error % values were 9.72, 2.40, and −2.68% for local, standard, and published equations, respectively. On the other hand, the standard volume equation was most precise in terms of mean absolute error %; the local volume equation was second.

Local and standard equations provided similar predicted *chip volumes*. Mean error % values were −11.38, −25.38, and −91.21 for local, standard, and published equations, respectively. Local and standard equations provided better diameter class estimates than the published equation in 8 of the 11 DBH classes, with the local equation performing better than the standard equation in 5 of 8 DBH classes. Mean absolute error % showed that the local volume equation was the most precise.

Merchantable volume was obtained by summing the predicted sawlog, chip-n-saw, and chip volumes for each of the three methods. Mean error % and mean absolute error % for merchantable volume are shown in Table 5. Predicted merchantable volumes from the local volume equations were most reliable in terms of both mean error % and mean absolute error %.

Data from all seven plantations were pooled together for determining final coefficients for the local volume equations. The resulting local product volume table (Table 6) can be used in most areas of northwest Louisiana.

Conclusions

Although standard and published equations utilized accurate height measurements in this study (obtained from felled trees rather than field etimates), their performance did not exceed that of local equations. Reliable product volume estimates were derived from equations requiring DBH only. Local equations performed best when predicting sawlog, chip, and total merchantable volumes and were comparable to a standard volume equation in predicting chip-n-saw volume. Consequently, local product volume equations can be used effectively in pine plantations that have reached the multiproduct stage of development.

Literature Cited

Burkhart, H. E. 1977. Cubic-foot volume of loblolly pine to any merchantable top limit. South. J. Appl. For. 1:7-9.

Smalley, G. W. and D. R. Bower. 1968. Volume tables and point-sampling factors for loblolly pine in plantations on abandoned fields in Tennessee, Alabama, and Georgia highlands. U.S. For. Serv. Res. Pap. SO-32, 13 p.

Appendix 1. Program PRODUCT.

Program PRODUCT was written in IBM BASIC to be run on an IBM personal computer. It can be easily modified for other personal computers. This program provides product volumes per acre for each diameter class from a user-supplied stand table.

Input: Number of trees per acre for each DBH class.

Output: For each diameter class:
—Pulpwood volume in cords per acre.
—Sawtimber volume in Doyle board feet per acre.
—Inside bark volume to a 3-inch top in cubic feet per acre.
—Green weight to a 3-inch top in pounds per acre.

Conversion Factors:
—1 cord = 82 cubic feet (Williams and Hopkins 1969,[1] Table 2, page 5).
—Conversion factor from cubic feet to Doyle board feet ranges from 2.30 to 6.10, depending on dbh (Williams and Hopkins 1969, Table 35, page 30).
—Green weight was obtained by first converting cords and board feet to pounds and then summing.
1 cord = 5,200 pounds (Williams and Hopkins 1969, page 46).
1 Doyle MBF = 17,754 pounds (Williams and Hopkins 1969, Table 59, page 51).

[1]Williams, D. L., and W. C. Hopkins. 1969. Converting factors for southern pine products. LSU Agric. Exp. Sta. Bull. 626, Rev., 89 p.

An example output of program PRODUCT:

Diameter at breast height (inches)	Trees per (acre)	Pulpwood (Cords)	Sawtimber Doyle (bd.ft.)	Volume ib ---to a 3-inch top (cu.ft.)	Green Weight --- (pounds)
3	8.0	0.00	0	0.0	0
4	36.0	0.00	0	0.0	0
5	88.0	2.53	0	207.3	13146
6	143.0	5.78	0	474.2	30072
7	159.0	9.78	0	801.9	50852
8	111.0	9.35	0	766.4	48602
9	45.0	4.85	0	398.0	25237
10	9.0	0.98	95	121.7	6780
11	1.0	0.09	25	16.7	914
Total	600.0	33.36	120	2786.1	175603

A listing of this program can be found in Appendix 2. If desired, send an IBM PC formatted diskette (5 1/4") to either of the authors for a copy of this program.

Appendix 2. Listing of program PRODUCT.

```
100 '    ***********************************************************
110 '    *                                                         *
120 '    *  Program PRODUCT provides product volumes per acre for each  *
130 '    *  dbh class from a given stand stable.                   *
140 '    *                                                         *
150 '    ***********************************************************
160 '
170 DIM TPA(50), FACTOR(50)
180 CLS
190 FOR D = 10 TO 25 '                 Read cu.ft. to Doyle conversion factor.
200    READ FACTOR(D) '                Williams & Hopkins, Table 35, p.30.
210 NEXT D
220 DATA 2.3, 2.7, 3.0, 3.4, 3.7, 4.0,
         4.2, 4.4, 4.7, 4.9, 5.1, 5.3,
         5.5, 5.7, 5.9, 6.1
230 CLS
240 DMAX = 0
250 PRINT "Enter stand table: DBH and trees per acre (TPA) for that DBH class"
260 PRINT "Example:    10,50     means 50 TPA at 10 inches."
270 PRINT "Enter:       0,0      when finish stand table input."
280 PRINT
290 INPUT "Enter DBH,TPA: ", D, TPA(D)
300 IF D > DMAX THEN DMAX = D
310 IF D > 0 THEN 290
```

Appendix 2. (Continued).

```
320 CLS
330 PRINT "Enter title for this table:"
340 INPUT "", TITLE$ '                    Print output?
350 KPRINT = 0
360 INPUT "Do you want the output printed? (Y/N) ", X$
370 IF X$ = "Y" OR X$ = "y" THEN KPRINT = 1 : GOTO 400
380 IF X$ = "N" OR X$ = "n" THEN 400 ELSE 360
390 '
400 CLS '                                 Print headings.
410 '
420 A$ = "  ============================================================================
======"
430 B$ = "   Diameter at   Trees              Sawtimber    Volume ib  Green we
ight"
440 C$ = "  breast height   per   Pulpwood       Doyle       ---to a 3-inch top
----"
450 D$ = "    (inches)     (acre)  (Cords)     (bd.ft.)     (cu.ft.)     (poun
ds)"
460 PRINT TITLE$ : PRINT
470 PRINT A$ : PRINT B$ : PRINT C$
480 PRINT D$ : PRINT A$ : PRINT
490 IF KPRINT = 0 THEN 560
500 LPRINT TITLE$ : LPRINT
510 LPRINT A$ : LPRINT B$ : LPRINT C$
520 LPRINT D$ : LPRINT A$ : LPRINT
```

Appendix 2. (Continued).

```
530 E$ = "    ######.# ####.##     ########        #######.#      ########"
540 F$ = "  #######" + E$
550 G$ = "    Total" + E$
560 '
570 SUMTPA = 0 '                            Initialize variables.
580 SUMCDS = 0
590 SUMBF = 0
600 SUMCF = 0
610 SUMLBS = 0 '                            *************************************
620 FOR D = 1 TO DMAX '                     *  Loop for DBH class.              *
630    IF TPA(D)  = 0 THEN 1000             *************************************
640    D2 = D*D
650    V3 = .283 + 51.8171/D2 '             Chip volume in cubic feet.
660    IF D < 5 THEN V3 = 0
670 '
680    IF D > 9.5 THEN 760 '                *********  DBH LE 9.5  *********
690 '
700    V5 = -11.0608 + 2.1091*D '           Chip-n-saw volume in cubic feet.
710    IF V5 < 0 THEN V5 = 0
720    V8 = 0
730    GOTO 810
740 '                                       *********  DBH GT 9.5  *********
750 '
760    V5 = .1237 + 798.915/D2 '            Chip-n-saw volume in cubic feet.
```

Appendix 2. (Continued).

```
770     V8 = -41.6645 + 4.627*D '            Sawtimber volume in cubic feet.
780 '
790 '                                        ***  Convert volumes to BF and lbs  ***
800 '
810     TV = TPA(D) * (V3+V5+V8) '           Merchantable cu.ft. volume to a 3-inch
820 '                                        top.
830     CORDS = TPA(D) * (V3+V5)/82 '        Cord volume (sum of chip and c-n-s).
840 '                                        Williams & Hopkins, Table 2, p. 5.
850 '                                          1 standard cord = 82 cu.ft.
860     IF D > 25 THEN FAC = FACTOR(25)
                  ELSE FAC = FACTOR(D)
870     DOYLE = TPA(D) * FAC * V8 '          Doyle BF volume from sawtimber.
880 '
890     WT = 5200*CORDS + 17.754*DOYLE '     Green weight in pounds.
900     SUMTPA = SUMTPA + TPA(D) '             Williams & Hopkins, p. 46.
910     SUMCDS = SUMCDS + CORDS '                1 cord = 5200 lbs.
920     SUMBF = SUMBF + DOYLE
930     SUMCF = SUMCF + TV '                   Williams & Hopkins, Table 59, p. 51.
940     SUMLBS = SUMLBS + WT '                   1 Doyle MBF = 17,754 lbs.
950 '
960     PRINT USING F$; D, TPA(D),
              CORDS, DOYLE, TV, WT
970     IF KPRINT = 0 THEN 1000
980     LPRINT USING F$; D, TPA(D),
               CORDS, DOYLE, TV, WT
```

Appendix 2. (Continued).

```
990 '                                      ****************************************
1000 NEXT D '                              *  End DBH loop.                       *
1010 PRINT A$ '                            ****************************************
1020 PRINT USING G$; SUMTPA, SUMCDS,
         SUMBF, SUMCF, SUMLBS
1030 IF KPRINT = 0 THEN 1060
1040 LPRINT A$
1050 LPRINT USING G$; SUMTPA, SUMCDS,
          SUMBF, SUMCF, SUMLBS
1060 END
```